UNDERSTANDING NORMAL AND ATYPICAL OPERATIONS THROUGH ANALYSIS OF FLIGHT DATA

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Over the past several years, airlines have initiated or participated in a number of safety data programs. Each involves collection of voluntary safety reports or the monitoring of flight data. These initiatives grew from recognition that mitigating safety risks requires monitoring a variety of data streams – reports, observations, and flight data. They have spawned technologies within air carriers, including Airline Safety Action Programs (ASAP), Line Operational Safety Audits (LOSA), improved analysis of training and checking data through the Advanced Qualification Program (AQP), and Flight Operational Quality Assurance (FOQA) programs. NASA has supported development of an Aviation Performance Measuring System (APMS) to facilitate development of advanced concepts and prototype software for the analysis of flight data, in order to further FOQA programs toward the proactive management of safety risk. This paper will discuss the functions that can be served by flight data analysis, describe the development of tools for those functions, and review applications of these tools which advance knowledge gained from flight data.

Sophisticated and labor-efficient processing and analysis of flight data will play a key role in understanding the risks represented by safety hazards and error in the National Aerospace System. Flight data may identify precursors of incidents and accidents and the context making consequences more and less likely. Risk assessment through flight data will require understanding the parameters of normal and routine operations, identifying atypical flights, detecting exceedances (situations in which parameters exceed limits for a phase of flight), spotting indications of actions contrary to procedure, and analyzing abnormal or emergency operations. Historically, the industry has examined exceedances first, because of their assumed proximity to incidents and accidents and the limitations of computer storage and processing. Exceedances are deviations from defined expectations, which may or may not be normative. That is, exceedances may occur routinely at some locations – we do not know in advance anything about their distribution. We would be more effective in achieving our goals if we understood the distributions of and associations among all parameters in normal operations before searching for indications of risk. At the very least, deviations from normative criteria are easily presented with visualization tools. But as an industry, we have pursued that which can be accomplished within available technology, and then expanded capabilities as computer power and storage have advanced. The result has been highly sophisticated data collection accompanied by very modest analysis.

While the available technologies for managing and processing data have improved dramatically, FOQA programs have moved only minimally beyond the analysis of exceedances. And in fact, their processing remains labor intensive, typically taking all the FOQA analyst's time. The mission of APMS thus has three major thrusts– moving beyond exceedance-detection to routine analysis of all of the data for safety and efficiency, providing focused analysis of higher risk phases of flight, and mining for atypical, potential precursors of incidents and accidents. Our goal is to focus the limited time of the domain expert on analyzing the most operationally significant events. Work has progressed in each area, resulting in the ability to examine distributions of routine events in each phase of flight, examine critical performance measures during specific phases such as landing rollout, and identifying meaningful clusters of flights within each phase. These advancements have been applied to identifying atypical approaches worthy of further examination by subject matter experts and to detecting and examining the consequences of changes in approach and runway assignment.

Advanced Analytical Tools

Since its inception in 1993, APMS has developed a number of tools. The first were designed to assist the day-to-day management of FOQA programs and include an event processing system, graphical viewer with single-button links to animation and performance envelopes, and an exceedance report generator. Subsequent tools were driven to advance the depth of analysis. Two – Pattern Search and Routine Events – have been completed and are being tested by airline partners.

Pattern Search enables an analyst to search the entire, or any portion of a database for a specified pattern of flight parameters (or time sequence of patterns). The user specifies the criteria defining an event, such as an unstable approach, and the search provides a list of flights fitting the pattern.

Routine Events documents the distribution of key parameters relevant to standard operating procedures at specific points during a flight. For approach, for example, these are tied to stabilized approach criteria and reveal how closely a group of flights comply with those criteria, by plotting the distribution of airspeed, localizer deviation, glideslope deviation, vertical speed, and N1 at 1,500, 1,000, 500, and 100 feet above the runway. Stabilized approaches will group together around the mean on each distribution. Unstable approaches will gravitate towards the tails of the distributions on one or more parameters.

Three additional tools are nearing completion; phase of flight reports, data integration, and atypicality analyses. Phase of flight reports present key descriptive statistics by phase of flight and user-selected sample characteristics. For example, a landing rollout report will provide mean, variability, and distributions of time and distance to spoiler deployment, thrust reverser application and retraction, brake application, and deceleration to 30 knots. Data integration allows the linkage of a flight to the weather or air traffic data at any time within the flight, while screening from the display time and date information that would identify the flight to the analyst. This information is immediately useful to examining the context of a flight with an exceedance. The implications will likely be broader, facilitating the understanding of consequences of the weather and traffic situations to which flight operations are exposed. Weather integration has been demonstrated; air traffic integration is under development.

Atypicality analysis will result in the production of a Morning Report (Amidan & Ferryman, 2000). This function uses multivariate cluster-analysis to group flights by similarity along flight signatures derived from parameter values, calculates an atypicality score for each flight, and provides a plain-language description of what makes targeted flights atypical (Willse, Ferryman, Cooley, & Amidan, 2000; Amidan & Ferryman, 2002). The distribution of atypicality scores – a function of the Mahalanobis distance from the population multivariate data centroid and multivariate cluster results – is used to identify flights for examination. The Morning Report provides a list of the most atypical 20% of flights, each time data is uploaded. This results in analysts working flights likely to be worthy of attention. Atypical flights may or may not capture exceedances, and could supplant exceedance analysis as a primary FOQA activity.

Applications

Amidan and Ferryman (2002) completed exploratory cluster and atypicality analyses for takeoff and approach phases of 1300 flights operating between a number of U.S. airports. Parameters were reduced to flight signatures during flight between takeoff power application and gear retraction on takeoff and between 1500 and 500 feet above touchdown on approach. When applied to takeoff, the analysis grouped flights by power setting, takeoff speed, flap setting, and correlates of length of takeoff roll, implying differences in aircraft weight and prevailing winds. The most atypical flights used non-standard flap settings.

More dramatic differences among flights were identified during approach. Approximately 80% of the flights clustered into five typical clusters reflecting relatively small differences in airspeed, power setting, flap position, and glide path. The first cluster was the most typical, accounting for roughly 30% of flights. These flights could be described as operationally routine, with parameter values very consistent with the airline’s approach procedures. Compared to these flights, the remaining typical clusters differed by reflecting reduced flap setting, maximum flap setting, higher airspeed, and higher airspeed and approach angle, respectively.

In contrast, the remaining 20% of flights clustered into five more atypical clusters differing markedly from the first five in heading relative to runway, roll attitude, and localizer and glideslope deviation. Compared to typical clusters, atypical flights were maneuvering to the extended centerline of the landing runway between 1500 and 500 feet above touchdown. Atypical clusters differed from each other in the degree of maneuvering during this phase. These maneuvers may represent differences in procedures among airports or in clearances assigned to individual flights. Amidan and Ferryman did not have access to the exceedances identified among these flights, but a key question for this process will be whether it identifies the most critical exceedances. Analyses using larger samples of data are necessary to truly explore the meaning of these differences, but this application suggests that the technique points to interesting flights worthy of application of attention by subject matter experts.

Chidester, Lynch, Lawrence, and Lowe (2002) reported the results of applying APMS tools to understanding the consequences of approach and runway assignment changes. This was part of a larger project in which NASA tasked each of its Aviation System Monitoring and Modeling programs to demonstrate, in its respective operational environment, the ability to aid causal analyses and safety risk assessment for a single issue or problem (Statler, Morrison, & Rosenthal, this volume). Anecdotal reports to the Aviation Safety Reporting System (ASRS) served as a starting point for identifying an issue for further examination. ASRS analysts had observed a number of reports describing problems encountered by pilots in accommodating changes to clearance while on approach and relatively close in to an airport. Three general categories of change were reported:

- Close-in change to a parallel runway
- Change to a parallel, intersecting, or reciprocal runway while operating in the terminal area
- Change in assignment during arrival.

Pilots can usually accommodate these clearance changes, but sometimes they produce unwanted consequences, such as lateral and vertical navigation deviations, traffic conflicts, unstable approaches, hard landings, or aircraft damage. Anecdotal reports offered hypotheses about factors that make negative consequences more likely, including ATC policies, actions of individual pilots and controllers, air carrier policies, aircraft type, and airport characteristics.

APMS sought to provide insight into these events by examining flight data to identify runway assignment changes when they occur, quantify associated contextual factors (such as location, distance, and traffic pattern), and quantify the frequency and severity of consequences. Application of Pattern Search provided an ability to identify flights with approach and runway assignment changes during the arrival, while operating in the terminal area, and close in to the airport. Statistics provided by the Routine Events tool and frequencies of exceedances allowed the assessment of consequences for those flights.

Analyses revealed that while flights with change in approach and runway assignment did not differ in rate of exceedances, they differed on average and variability on several parameters during the approach.

- Flights experiencing a close-in change showed greater localizer deviation at 1,500, 1,000, and 500 ft. afe., were higher on the glideslope at 1,000 ft. and lower at 500 and 100 ft., and had greater nose-down pitch at 500 and 100 ft. These flights were more variable on the localizer throughout the approach, in airspeed and vertical speed at 500 and 100 ft., and N1 at 100 ft. (all probabilities < .01). Localizer and glideslope differences may need to be discounted among these flights as about one-third navigated visually to the new runway, rather than change ILS frequencies.
- Flights experiencing change in the terminal area showed greater localizer deviation throughout the approach and greater nose-down pitch at 100 ft. These flights were more variable on the localizer at 1,000 and 500 ft. and in vertical speed at 100 ft. The ILS receiver was retuned to the new runway on all these flights.
- Flights experiencing change during the arrival showed higher airspeed at 1,500 and 1,000 ft. These flights were more variable on the localizer throughout the approach, in airspeed and N1 at 500 and 100 ft., and vertical speed at 100 ft. The ILS receiver was retuned to the new runway on all these flights.

In most cases, those differences made the approach less stable. Flights with changes close in to the runway were less stable than those receiving changes within the terminal area but above 2500 feet, or during the arrival.

However, flights with a change were not so extremely destabilized as to trigger unstable approach criteria, suggesting the risk is not extreme. Stabilized approach criteria have been applied by the industry to deal with findings from approach and landing accidents, implying that less stable approaches present a greater risk. Findings from the study suggest that approach and runway assignment changes result in less stable approaches, implying somewhat greater risk.

Chidester, et al, also noted some limitations to those conclusions. Because their analyses focused on arrivals to a single airport, they did not identify circling maneuvers or changes to intersecting or reciprocal runways among terminal area approach/runway change flights. The airport conducted approaches to parallel runways; changes were among the parallels. Review of ASRS reports suggested that changes to intersecting or reciprocal runways might present the most difficulty. Comparable analyses at other airports would likely identify intersecting or reciprocal runway assignment changes and allow exploration of their consequences. However, flight data cannot by itself characterize all the contributing factors, context, or consequences. For example, Shade, Abkin, Davis, and den Braven (2002) conducted a parallel analysis using ATC radar data and found that flights completing a close-in approach change crossed the runway threshold at a higher altitude. Because the flight data they analyzed did not record latitude and longitude with sufficient accuracy, Chidester, et al, could not observe this. Further, both flight and radar data are objective and provide none of the perspective of the pilots or controllers involved in a runway change. For example, neither dataset indicates who *initiated* the assignment change. All of the changes observed in flight data were to operationally advantageous runways – from an outboard to an inboard runway, or from a complex far from to a complex close to the airlines' gates. This suggests a motive for both pilots and controllers to request and carry out approach and runway assignment change. The more general point of this discussion is that perspectives from multiple data sources are necessary to understand and solve operational problems.

Conclusions

Flight data analysis offers much promise toward the proactive management of safety risk by operators, but this will require more sophisticated and more automated analysis tools. APMS has developed several tools to advance these capabilities, including the ability to search for patterns and sequences of parameters and document the distribution of key parameters at routine flight events. Additional tools are nearing completion, including presenting key descriptive statistics and distributions by phase of flight, de-identified linkage of a flight to the weather or air traffic data at any point within the flight, and automated identification of atypical flights. Applications of these new tools suggest their promise. Their ultimate utility will depend upon successful transfer into industry FOQA operations.

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